water supply

A water supply provides water for use in homes and industries, for irrigation, for extinguishing fires, for street cleaning, for carrying wastes to treatment facilities, and for many other purposes. The three most important factors in any water supply are its quality, the quantities available, and the location of the water supply relative to the points of use. Each type of water use has its own prerequisites. Food processing plants, for example, need large volumes and high water quality; waste conveyance systems require only volume.

A typical water-supply system consists of six functional elements: a source or sources of supply; storage facilities, such as impoundment reservoirs, transmission facilities for transporting water from the point of storage to the treatment plant; treatment facilities for altering water quality; transmission and storage facilities for transporting water to intermediate points, such as standpipes or water towers; and distribution facilities for bringing water to individual users.

The average water use in the United States in 1980 was 1,750 billion liters (460 billion gallons) per day withdrawn from underground and surface sources. Much of this water was returned to surface streams and groundwater after use, and therefore the total consumptive use was only 22% of the volume withdrawn. Instream nonconsumptive use for hydroelectric power was an additional 12,200 billion liters (3,200 billion gallons) per day.

SOURCES

Rainwater falls on a watershed (catchment area) and either flows above ground to streams and rivers or soaks into the ground to reappear in springs or to be drawn from wells (see HYDROLOGIC CYCLE). A water supply can come from a catchment area that may contain thousands of hectares of land draining to streams whose flow is retained in impoundment reservoirs. If a water supply is drawn from a lake or large river, the catchment area is the entire area upstream from the point of intake.

The amount of rainwater that will enter a water-supply system depends on the amount of precipitation and the volume of the runoff. The annual average precipitation in the United States is about 760 mm (30 in), of which two-thirds is lost to the atmosphere by evaporation and transpiration. The remaining water becomes runoff into rivers and lakes or, through infiltration, replenishes groundwater. Precipitation and runoff vary greatly with geography and season (see WATER RESOURCES).

Surface Water

Surface water is obtained from lakes, streams, rivers, or ponds. Storage reservoirs--artificial lakes created by constructing DAMS across stream valleys--can hold back higher-than-average flows and release them when greater flows are needed. Water supplies may be taken directly from reservoirs or from locations downstream of the dams. Reservoirs may serve other purposes in addition to water supply, such as flood mitigation, hydroelectric power, and water-based recreation.

Groundwater

GROUNDWATER supplies come from natural springs, from wells, and from infiltration galleries, basins, or cribs. Most small, and many large, North American water systems use groundwater as their source of supply.

Groundwater may be drawn from the pores of alluvial, glacial, or aeolian deposits of granular unconsolidated material, such as sand and gravel; from the solution passages, caverns, and cleavage planes of sedimentary rocks, such as limestone, slate, and shale; and from combinations of these geologic formations. Groundwater sources may have intake or recharge areas that are kilometers away from points of withdrawal (water-bearing stratum or aquifer). About half the population in the United States derives drinking water from groundwater sources.

Water Reuse

Only a small portion of the water supplied to dwellings, commercial and industrial establishments, and public facilities is consumed by evaporation and processing. The remaining wastewater (usually after treatment) is discharged into the soil and infiltrates to groundwater or is discharged to surface watercourses. Commercial and industrial firms use most of their water supplies for cooling, after which the water may be recycled. Pioneering work on wastewater reclamation and reuse in the United States has taken place in the southwest, particularly in southern California with its large population, extensive irrigation, and limited fresh water. The major reuses have been for

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cooling purposes and for irrigation of selected crops.

TRANSMISSION AND DISTRIBUTION SYSTEMS

Water from a river, lake, or reservoir flows through an intake structure into the transmission system. The intake pipe from a groundwater source is usually connected to a pump and transmission conduit that conveys the water to a distribution system. Surface- and ground-water supply systems may contain canals, pipes, and other conveyances; pumping plants; distribution reservoirs or tanks to assist in balancing supplies and demands for water and to control pressures; other appurtenances; and treatment plants.

Transmission

A good example of a large city's water-supply and transmission system is that of New York City. This complicated system draws water from as far as the east branch of the Delaware River and conveys the water in gravity tunnels that were once considered the second most impressive engineering feat in the history of the United States (the Panama Canal rated first). The New York City system was begun in 1830 with the building of the Croton Reservoir, an impoundment of the Croton River. The reservoir was completed in 1842 and captured the flow from a watershed draining 975 sq km (375 sq mi). The system has grown along with the population. Plans have been proposed for the construction of a third tunnel from the Ashokan Reservoir, for taking water from the Hudson River, and for trading water between adjacent water-supply systems of the metropolitan New York area in order to increase their reliability in times of drought.

Distribution

In cities the distribution system generally follows the street patterns, but it is also affected by topography; types of residential, commercial, and industrial developments; and location of treatment facilities and storage works. A distribution system is often divided into zones corresponding to different ground elevations and service pressures. The water pipes (mains) are generally in closed loops so that supply to any point can be provided from at least two directions. Street mains usually have a minimum diameter of 15-20 cm (6-8 in) to provide adequate flows for buildings and for fighting fires. The pipes connected to buildings may range down to as small as 2.5 cm (1 in) for small residences.

WATER TREATMENT

All natural waters contain inorganic and organic substances. The types and amounts of these substances depend upon exposure to physical, chemical, and biological actions in the hydrologic cycle (for example, addition of sediment from erosion) and contamination by pollutants caused by human activities. The treatment of water supplies depends on the quality of the source of the surface water or groundwater and the standards established for a specific purpose.

Many water supplies can be used with little or no treatment for cooling and for many types of agriculture. Substantial treatment may, however, be needed for some types of industrial processes and for domestic uses. All public water supplies must meet the standards established by the 1974 Safe Drinking Water Act, which relate to physical and chemical characteristics and to pesticide contaminants. These standards are updated periodically by the Environmental Protection Agency to take account of continuing investigations of the health and economic effects of various constituents of water.

Water-treatment plants are generally designed to remove the following principal contaminants: pathogenic bacteria, trace organic compounds; substances producing color, taste, and odor; suspended materials; and minerals causing hardness. For instance, iron concentrations in excess of 0.3 mg/l can cause stains on laundry. Sulfate concentrations in excess of 250 mg/l have a laxative effect on humans, and chloride concentration in excess of 250 mg/l impart an unpleasant taste to the water. Water containing 10 mg/l or greater of nitrate nitrogen can cause methoglobenemia in babies. The pesticides lindane, endrin, methoxychlor, toxaphene, and silvex are suspected of causing cancer. To meet drinking-water standards, water is treated by any number of combinations of processes that can be broken down into two distinct categories, physical and chemical.

Physical Treatment

The most common methods of physical treatment are screening, aeration, flocculation, sedimentation, and filtration. Screening usually requires the use of coarse screening or bars 2.5 to 5 cm (1 to 2 in) apart to remove

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large floating and suspended debris from the water. Microscreens, another type of screening that may be used farther on in the process, are drumlike fine-mesh screens (23- to 65-micron aperture sizes) designed to remove fine suspended material. Aeration is a gas-transfer operation used to remove carbon dioxide and hydrogen sulfide, and to oxidize dissolved iron and manganese and volatile oils (such as taste and odor substances). This may be accomplished by waterfall cascades, spray or fountain aerators, mechanical aeration (mixing), and injection of air into the water.

Flocculation is a gentle agitation of flocculant precipitates that result from the addition of coagulant chemicals. The purpose of this gentle agitation is to conglomerate particulates into large clumps that will settle. Sedimentation removes particles from the water by allowing them to settle in a tank. Filtration removes finely suspended material from the water by use of a layer of sand--or sand with crushed coal--supported by a gravel bed.

Chemical Treatment

The more common methods of chemical treatment include coagulation, disinfection, water softening, adsorption, and oxidation. Coagulation involves the addition to water of a chemical that induces the formation of precipitates of fine and colloidal suspended material. This material forms flocs with a particle size of sufficient density to be removed by settling in a sedimentation basin.

A common coagulant chemical is alum, which is used to precipitate particulate substances out of the water. Disinfection is the destruction of pathogenic organisms in a water supply. Chlorine is the most commonly used disinfectant, and chlorination is usually the last step in a water-treatment system. There are times, however, when prechlorination is needed in order to destroy algae, oxidize excessive levels of organic load, improve coagulation, and reduce the load on filters in the system. Prechlorination has its drawbacks, however, because chlorophenol compounds can form if the incoming water contains phenols and impart a disagreeable taste to the water; this is prevented by the addition of ammonia to water prior to chlorination. The extent of chlorination is being reduced because of evidence of the formation of cancer-causing compounds in chlorination.

Water softening (see WATER SOFTENER) is the removal of hardness (calcium and magnesium) from water by the addition of lime and soda ash. Another process is ion exchange, in which the calcium and magnesium in water are exchanged for sodium in a resin-filter medium.

Adsorption is a process for removal of organic chemicals--some of which cannot be removed by conventional water-treatment processes--by activated carbon. Adsorption is the clinging of materials to the surface of the carbon granules. Activated carbon presents a tremendous amount of surface area in relation to the net volume of granules used.

Oxidation is carried out by chemical reactions that convert undesirable substances to less-harmful forms. A good example is the conversion of cyanides to cyanates by the use of ozone.

DESALINATION (desalting), the conversion of saline water to fresh water, is a technique that is increasingly used where freshwater supplies are insufficient. In the mid 1980s more than 1,500 desalination plants throughout the world (many of them situated in the Middle East) were producing a total of more than 7.5 billion l (2 billion gal) per day of fresh water from saline waters. This is accomplished through distillation, freezing, demineralization by ion exchangers, electrodialysis, or reverse osmosis.

WASTEWATER COLLECTION AND DISPOSAL

Wastewater Collection

Seventy to ninety percent of the water distributed in a community by a public water-supply system is discharged after use to wastewater collection and disposal systems. In small communities, disposal is often by individual building facilities, such as septic tanks and tile fields that extend into the soil. In larger cities, and in small communities where soil conditions are not appropriate for individual systems, extensive piping systems, following the street alignments, accept wastewater discharges and lead to wastewater treatment plants. While water-distribution systems operate under water pressure, the pipes in the wastewater-collection systems are usually placed on down slopes to sustain gravity flow.

Wastewater Disposal

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Wastewater Disposal

Wastewater can be treated by a number of systems. The conventional method, however, is a combination physical-chemical-biological system that removes specified amounts of organic matter, nitrogen, phosphorus, and other material that may be contained in the wastewater. A typical plant would include primary settling tanks for the removal of readily settleable solids. This stage is usually followed by a biological treatment unit, such as a trickling filter or an activated sludge-aeration tank, in which microorganisms digest the organic matter in the waste and develop cell mass while reducing concentrations of organic wastes. The waste stream then enters a sedimentation basin in which the cell mass and other suspended materials are settled out. The water that leaves this basin is then chlorinated and discharged to a receiving stream or other water body. There are many other types of systems that provide for treatment of domestic and industrial wastewaters. (See SEWERAGE; WASTE DISPOSAL.)

CRITICAL WATER-SUPPLY ISSUES

Problems of inadequate water and sanitation facilities exist throughout the world and have been particularly acute in the poorer countries. The World Health Organization estimated that at the end of 1975, 25% of the people in developing countries had no access to potable water by house connections or standpipes. In rural areas, almost 80% did not have reasonable access to safe water. Considering both rural and urban populations, only 35% were adequately served. Although many new systems have been constructed in recent years, the growth of population has imposed even greater needs, and there has probably been little overall improvement.

In the economically advanced countries, close to 100% of the urban population and most of the rural population is served by safe and dependable supplies. Most water-supply systems in the United States have dependable supplies, control waterborne disease, and provide water without unacceptable color, odor, and taste. Despite this general situation, critical problems of water supply exist in various locations in the United States.

Competing offstream uses of water for energy, agriculture, and municipal and industrial needs, coupled with associated environmental and instream flow requirements (for hydroelectric power, for example), have caused severe basinwide and local problems. Diminished water pressure, declining spring and stream flow, land subsidence, and saltwater-intrusion problems have resulted from excessive withdrawals of groundwater.

Pollution in watercourses used for water supplies is a problem in many areas, caused by direct and indirect discharges of municipal and industrial wastes and by surface runoff from rainfall on urbanized, agricultural, and mining areas. Groundwater pollution is recognized increasingly as a serious problem, due to contamination from animal feed lots, community land fills, toxic and hazardous materials, septic tanks and cesspools, and municipal and industrial discharges. Once contaminated, groundwater recovery is typically slow, and the cost of treating water from such sources is high.

At least 4,000 cases of waterborne illnesses, primarily of bacterial or viral origin, are still reported each year, but the actual total, including more-difficult-to-identify chemical poisonings, is larger. Medical science has begun to address the issues of chemical carcinogens that involve latency periods of 20 or more years before disease symptoms can be identified, as well as problems of acute chemical toxicity. With the emphasis on more-intensive use and reuse of available water supplies, quality improvement could become an increasingly important issue.

DEVELOPMENT OF PUBLIC WATER-SUPPLY SYSTEMS

Water-supply and disposal systems began with the growth of ancient cities. The earliest record of central water-supply and wastewater disposal dates back to the city of Nippur in Sumer, 5,000 years ago. Water there was drawn from wells and cisterns, and arched drains provided an extensive drainage system that conveyed the wastes from palaces and residential areas of the city.

Water-treatment knowledge dates from 2000 BC, when Sanskrit writings indicate that methods for purification of foul water consisted of boiling in copper vessels, exposing to sunlight, filtering through charcoal, and cooling in earthen vessels.

The most notable ancient water-supply and waste-disposal systems were those of Rome. In AD 97, Sextus Julius FRONTINUS, then water commissioner of Rome, reported the existence of 9 aqueducts of lengths varying from 16 to more than 80 km (10 to 50 mi), with cross sections of 0.5 to 4.5 sq m (7 to 50 sq ft). Such a system had an estimated aggregate capacity of 84 million gallons per day. In addition to this system, Rome had a great sewer known as the Cloaca Maxima, which drained the Roman Forum, and which is still in service.

The strides in water supply and waste disposal in ancient times were notable; quality control and public health

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practices, however, are of recent origin. The industrial revolution of the 18th and 19th centuries created industrial centers to which people flocked for employment. Because of inadequate city water-supply and waste-disposal systems, disease began to increase significantly. Water was drawn from polluted rivers and shallow wells contaminated by untreated, disease-bearing sewage.

The large cities had been provided with extensive storm drainage systems, and the discharge of human wastes into them had been forbidden until the crowding in the cities, which caused sanitation problems of monumental proportions, forced their use. The use of the storm drains offered a cheap and ready way to ease the problems of overcrowding; the simple conveyance of sewage from the city to nearby rivers, lakes, and tidal estuaries, however, only transferred the problem to these bodies of water, and they became heavily contaminated with pathogenic organisms. Because these water bodies supplied the cities with water, the contamination resulted in the persistence of many types of disease.

Cholera appeared in London in 1848 and claimed 14,600 lives the next year and 10,675 lives in 1854. The spread of the disease was linked to the contaminated water supply, and the control of the disease was hindered by the lack of sewers. Finally, in 1855, an act of Parliament provided the basis for the Metropolitan Commission of Sewers to provide an adequate system.

In the United States the growth of population from 2.5 million at the time of the American Revolution to more than 200 million and the conversion from an essentially rural economy to about 25% urban population after the Civil War and to some 75% urban population today, has required the extensive development of public water-supply systems. In the second half of the 19th century and the early part of the 20th century, concern with the quality of these supplies became dominant as the result of serious outbreaks of waterborne disease. More than 50,000 people died from typhoid fever due to contaminated water in a five-year period from 1900 to 1904.

Whereas filtration was employed in Europe as early as 1829, it was not used in the United States until 1871, when large filters were installed in Poughkeepsie, N.Y. Even by 1900, only 10 filtration plants were in operation. The reliability of water treatment increased greatly when disinfection began to be employed, first in 1908 with chlorine compounds and then from 1911 when chlorine gas was introduced. By the 1930s, due both to better protection of sources of water and to chemical disinfection, waterborne diseases were largely eliminated from U.S. cities.

The historical problems of waterborne diseases would have been much worse if it were not for the development of uncontaminated water supplies requiring little or no treatment. Thus, groundwater supplies have been used when they were adequate, particularly for small cities. Many of the larger cities have developed large surface-water supplies from remote catchment areas protected from contamination. The Boston metropolitan area, since 1930, has been served by a system dependent on tributaries of the Connecticut River.

Other large 20th-century interbasin river-transfer developments for municipal and industrial water supply and for other purposes have included the Colorado River aqueduct serving the Los Angeles metropolitan district, the transmountain aqueducts carrying water across the Continental Divide to Denver, the aqueduct system to transfer Delaware River water to New York City, the Central Valley Project in Southern California using excess waters moved from the northern part of the state, and numerous water supplies from federal multipurpose reservoirs. Such long-distance transfers have not only sustained large urban population growths but have also made possible the irrigation of vast areas of farmland in rainfall-deficient regions, particularly in the southwestern United States.
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practices, however, are of recent origin. The industrial revolution of the 18th and 19th centuries created industrial centers to which people flocked for employment. Because of inadequate city water-supply and waste-disposal systems, disease began to increase significantly. Water was drawn from polluted rivers and shallow wells contaminated by untreated, disease-bearing sewage.

The large cities had been provided with extensive storm drainage systems, and the discharge of human wastes into them had been forbidden until the crowding in the cities, which caused sanitation problems of monumental proportions, forced their use. The use of the storm drains offered a cheap and ready way to ease the problems of overcrowding. The simple conveyance of sewage from the city to nearby rivers, lakes, and tidal estuaries, however, only transferred the problem to those bodies of water, and they became heavily contaminated with pathogenic organisms. Because these water bodies supplied the cities with water, the contamination resulted in the persistence of many types of disease.

Cholera appeared in London in 1849 and claimed 14,600 lives the next year and 10,675 lives in 1854. The spread of the disease was linked to the contaminated water supply, and the control of the disease was hindered by the lack of sewers. Finally, in 1855, an act of Parliament provided the basis for the Metropolitan Commission of Sewers to provide an adequate system.

In the United States the growth of population from 2.5 million at the time of the American Revolution to more than 200 million and the conversion from an essentially rural economy to about 25% urban population after the Civil War and to some 75% urban population today, has required the extensive development of public water-supply systems. In the second half of the 19th century and the early part of the 20th century, concern with the quality of these supplies became dominant as the result of serious outbreaks of waterborne disease. More than 50,000 people died from typhoid fever due to contaminated water in a five-year period from 1900 to 1904.

Whereas filtration was employed in Europe as early as 1829, it was not used in the United States until 1871, when large filters were installed in Poughkeepsie, N.Y. Even by 1900, only 10 filtration plants were in operation. The reliability of water treatment increased greatly when disinfection began to be employed, first in 1908 with chlorine compounds and then from 1911 when chlorine gas was introduced. By the 1930s, due both to better protection of sources of water and to chemical disinfection, waterborne diseases were largely eliminated from U.S. cities.

The historical problems of waterborne diseases would have been much worse if it were not for the development of uncontaminated water supplies requiring little or no treatment. Thus, groundwater supplies have been used when they were adequate, particularly for small cities. Many of the larger cities have developed large surface-water supplies from remote catchment areas protected from contamination. The Boston metropolitan area, since 1930, has been served by a system dependent on tributaries of the Connecticut River.

Other large 20th-century interbasin long-distance developments for municipal and industrial water supply and for other purposes have included the Colorado River aqueduct serving the Los Angeles metropolitan district, the transmountain aqueducts carrying water across the Continental Divide to Denver, the aqueduct system to transfer Delaware River water to New York City, the Central Valley Project in Southern California using excess waters moved from the northern part of the state, and numerous water supplies from federal multipurpose reservoirs. Such long-distance transfers have not only sustained large urban population growths but have also made possible the irrigation of vast areas of farmland in rainfall-deficient regions, particularly in the southwestern United States.
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